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HISTORY OF SUBMERGENT TUNNELS goes back to the year 1818 when Marc Brunel, a Frenchman, took out the first patent for the shield and caisson lining. About twelve years later, or in 1830, Sir Thomas Cochrane secured the first patent for compressed air. Between 1823 and 1843 Marc Brunel built the first subaqueous tunnel under the Thames near London. The tunnel was finished under the most difficult conditions without the use of compressed air. But this ambitious enterprise was a financial failure and checked all undertakings of a similar character for the next twenty-five years. It was not until James H. Ingershead developed the circular one-piece shield, invented the grouting machine, made use of compressed air and caisson lining that subaqueous tunnels were economically built.

The first vehicular tunnel of magnitude and capacity was the Blackwall Tunnel under the Thames in London, opened for traffic in 1897. Others were the Glasgow Harbor Tunnel, England, the Elbe Tunnel in Germany and the Rotherhithe Tunnel in England, the last completed in 1908.

All these tunnels were built previous to the advent of the automobile. As the automobile came into general use, the need for tunnels increased. The first motor vehicle tunnel in Pittsburgh, the George A. Posey Tube, between the cities of Oakland and Alameda, California and the Detroit and Windsor Tunnel under the Detroit River were built.

We will take a quick trip through the Detroit-Windsor Tunnel: Driving through the entrance on Woodbridge Street in Detroit, past the tollbooths and circling to the right, going northbound downward, a spiral driveway is taking us underground, now heading South. We are driving on a granite block roadway in a brightly lighted well ventilated whitelined tunnel. For about five hundred feet we are on a five percent grade and then we are leveling out for the trip under the river. At our right is the right-of-way sidewalk where guards are controlling the length of the tunnel. Midway under the river is a dividing mark showing in colored tile the flag of the United States and Canada. It is known as the world's friendliest border. A little beyond this point the tunnel is at its lowest point, the roadway we are on is 75 feet under the surface of the river. Above us is the water, the water is the sky. The tunnel is about five feet of clay and above that 45 feet of water. Beyond the boundary line we start going up, the slope becomes steeper and we are now beyond the water's edge, climbing a five percent grade toward daylight in Windsor, Canada.

That was a trip through the Tunnel. Now we shall learn how it was built: There are three methods of building a subaqueous tunnel. Outward, Earth, Shield and Trench-and-Tube. The outward cover method is the oldest, but it has many limitations. It is the most ground, cover it over, and you have a tunnel. That is the way subways are built, and that is how the Detroit-Windsor Tunnel was built from the entrance point, on either side of the river, fifty feet under ground.

The trench-and-tube method was used in the river bed itself, we will come to that later. We will learn how the shield method was used. First, you dig the ground, on the Detroit side of the river, about 150 feet back from the water's edge, 50 feet deep by about 40 feet square. It is a steel-lined shaft with elevators running up and down. At the bottom men are constructing the shield. This is not a new idea. Miners digging through sand and gravel can be protected from possible cave-ins and floodings. The shield gives them this protection. The Detroit-Windsor Tunnel shield was a hollow steel cylinder 32 feet 8 inches in diameter and 15 feet long. This shield lies on its side and across the open front end steel platforms and vertical partitions are built and in the holes thus formed miners are at work digging at the earth. But how is the water kept out if the shield has an open front end? The answer is compressed air. To the rear of the shield, not a part of the shield itself, is an air tight bulkhead, a steel plate. Built into this bulkhead are three ladders, these are called locks, two are for material and one for men. From the bulkhead to the shaft forward into the shield you have to go through the bulkhead. You enter the man-lock by an air-tight door and find yourself in a long tube-like room with another door at the other end. There you will have to wait with doors closed while a forcing pump fills the shield with compressed air. When the compressed air is in the air-tight room, you close the lock. The noise comes from the forcing pump at the rear of the bulkhead and the front by the earth. The compressed air is an inviolable force showing between the particles of dirt, forcing the water back; a marvelous force, pushing at the front end of the shield, holding back the water like a giant hand.

When you are on the surface you are living under a pressure of 14 pounds per square inch, which is normal atmospheric pressure. To keep the water out under a pressure four times that much. Only 18 pounds of pressure was necessary to keep the water out of the Detroit-Windsor Tunnel shield.

We will examine the shield more closely now. We will go to the rear of the shield, the back of the shield, on one end of the tube, sinking it below water. That end sunk to the bottom, but when you remember that the tube is 35 feet in diameter after the concrete has been poured and the river water is 45 feet above this point, you realize that the tube didn't have far to sink. With one end under water, a floatation scow was run over that end and attached to the tube by means of cables. A diver hooked the cables from the floatation scow to each side of the submerged tube end, then concrete blocks were placed on the other end, a floatation scow ran over that end and the tube was pulled. Now we have a submerged tube weighing about 8,500 tons. Into the bottom of the trench 2 1/2 feet of sand had been dropped and graded level. Now tube section 1 was ready to be placed into the trench on the American side of the river. When section 2 was lowered into the trench, the tube was on either side of the tube overlapped slightly placed lugs on section 1. A big steel pin, 5 inches in diameter, was dropped through these two lugs and a diver guided it into place. Concrete was poured over the joint (a complete collar of it) and the divers had to slip the forms into place and guide the "iron" pipe while the concrete was being poured. One of the most important parts of the concrete job was when the great section, 248 feet long and 35 feet in diameter, octagonal in shape, was dropped downstream 300 feet and swung broadside to the current over the trench. There is a two-mile current in the river and this tube, almost as deep as the river, will amply consider the current a flowing brookside. Four concrete anchors, each weighing 15 tons, were buried deep in the bottom of the river. Two of these anchors were placed off to one side, out midstream, opposite the downstream end of the tube, the other two were placed straight upstream from the tube. Between the upstream anchors and the tube a "puller scow"—which is a big scow with engines powerful enough to pull against the buried anchors and haul the tube back if it should drop downstream too far—was interposed.

There are nine sections of tube in the Detroit-Windsor Tunnel with a total length of 2,200 feet. The first six sections were laid downward, the last three slant upward to the Canadian shore. As each section was laid it was lined up by means of tall masts on each end of the tube.

The last important step in the completion of the tunnel was the joining of the shield-driven and tube sections; in other words, of land and river sections.

The landward end of the first section of the tube flares out with a bell-like way. Toward this opening the shield is steering its way through the ground. But obviously the shield can't dig its way through the open water of the trench. Compressed air won't keep away

will go forward and climb a ladder to one of the miner holes. A cut of the shield is of 2 1/4 inch steel. The front rim however is cast iron, tapered to five feet at the cutting edge. You watch a miner slicing off the clay in front of him with a draw knife. It is like clay, easy to handle, and he uses back long lugs which it onto a conveyor that takes it back to the rear where it is transferred to small cars standing on a narrow track.

Midway of the shield, on a transverse girder, there is a device called an erector arm. It looks like the handle of a clock, about 16 feet long, working on a pivot at the exact center of the shield. This is the tool the engineer uses for erecting the pressed steel rings which the tunnel is being lined as the shield moves forward. These rings come in segments and the erector arm swings them in place at the top, bottom or sides of the tunnel's circumference and holds them when workmen bolt them.

What force drives the shield through the earth? Around the circumference of the shield are 32 hydraulic jacks, each capable of exerting 100 tons pressure. Two of each jack rests against the last placed steel ring. When it is time to advance the shield, the erector arm swings them into action. The shield moves forward by 2 foot steps, just far enough to allow another steel ring to be put into place.

Here is a cross-sectional look of the shield in operation: Picture a hundred feet of tunnel. At the head of it is the shield with the men inside digging out the earth. The erector arm, running along the sides are cables and rings. Back of the shield is about 80 feet of completed tunnel, lined with pressed steel rings. At the rear of the tunnel is the air-tight bulkhead with its three locks for material and one for men. Running from the shield back through the material locks is the narrow air duct. Running along the sides of the shield are water pipes to feed juice to the electric lights and water to the hydraulic jacks. In back of the bulkhead is the elevator shaft leading upward to daylight.

Now we have a picture of the shield with the men working safely inside, protected by compressed air. But as the shield burrows slowly through the earth it must change its shape, change its sections both laterally and vertically. It means the shield must be able to turn horizontally, it needs a lot of steering power. The steering ahead through dense fog in the dead end of the ship.

The pilot rests on a small platform hanging from the top of the tunnel in back of the shield. With taut lines and level his sights on certain points in the shield. If he wants the shield to turn downward he orders the top hydraulic jacks into action. If he wants the shield to turn right he orders the left side jacks into action. And so the shield goes on, day after day

a solid wall of water, so dredgers may cover the landward end of the tube with clay to a depth of at least 15 feet. Through this backfill the shield borers its way. The shield forces solid ground and begins to expand into the muck of the backfill. The air pressure is increased to 21 pounds to keep out the water. As the shield entered the muck, workmen in the front end began to timber up the open end, and the shield was pushing blind through the muck, depending upon engineering science to hit exactly the bell opening of the tunnel. When the shield was in the muck, there was an inch of error. The shield had traveled 466 feet, changing both direction and altitude and ended up only an inch off its course.

Now, underneath the backfill, 31 feet out beyond the harbor line, the shield was forced tight against tube section 1. The skin of the shield was left there for a while as the walls of the tunnel were being built between each tube section were torn out. The 18-inch inner lining of concrete was poured at the joints. The sidewalk and granite-block pavement was laid, the walls were tiled, lighting and ventilation installed.

Ventilation is an important point. The tunnel can handle 1200 cars an hour each way, but autos produce a great deal of gas. Engineers figured that man can live comfortably in a room that has four parts of carbon monoxide in ten thousand parts of air but if the concentration were any greater he became fatigued. So the tunnel ventilation system does not permit a greater concentration than four parts to ten thousand parts of a self ventilating tower. The Detroit shield has another on the Windsor side. Each tower has twelve fans, six great blowers to force air into the tunnel and six exhausters to draw air out. The fans in each tower may be operated from a power supply from either side of the river. Fresh air goes into the tunnel through a duct alongside the roadway and is released through outlets over 15 feet high air is drawn out through ports in the roof also 15 feet apart. The tunnel ventilating system can supply 1,500,000 cubic feet of air a minute and completely change the air in the tunnel every 90 seconds.

Tunnel Statistics

Original Opening.....	November 3rd, 1919
Length of tunnel from American to Canadian ports.....	2,135 feet
Maximum depth of roadway below river surface.....	75 feet
Dirt excavated from river.....	275,000 cubic yards
Concrete poured.....	80,000 cubic yard
Width of roadway.....	22 feet
Capacity.....	2,400 cars per hour
Cost.....	\$23,000,000

building a subaqueous tunnel. Out-and Cover, Shield, and Tunneling will come in handy. The out-and-cover method is just what the name implies. You dig a trench, lay the shield on the ground, cover it over, and you have a tunnel. That is the way subways are built, and that is how the Detroit-Windsor Tunnel was built from the entrance points, on either side of the river, fifty feet under ground.

The trench-and-tube method was used in the river bed. The trench will come in handy later. We will learn about the shield's method first. Picking up the shield from the ground, on the Detroit side of the river, about 150 feet back from the water's edge, 50 feet deep by about 40 feet square. It is a steel-shaft built with elevators running up and down. At the bottom men are constructing the tunnel. This is not a new idea. Miners digging through sand and gravel have long been protected from possible cave-ins and floodings. The shield guided them this protection. The Detroit-Windsor Tunnel shield was a hollow steel cylinder 32 feet and 8 inches in diameter and 15 feet long. This shield lies on its side and across the open front end steel platforms and vertical supports are built into the holes thus formed miners are at work digging at the earth. But how is the water kept out if the shield has an open front end? The answer is compressed air. To the rear of the shield, not a part of the shield itself, is an airtight bulkhead of steel. Built into this bulkhead are two doors. These are called locks, two are for material and one for the compressed air coming from the shaft forward into the shield you have to go through the bulkhead. You enter the man-lock by an airtight door and find yourself in a long tube-like room with another door at the other end. There you will have a protection against the water. When you are in the shield you are in an airtight working tunnel, closed off at the rear by the bulkhead and the door at the front of the earth. The compressed air is an invisible force shoving between the particles of dirt, forcing the water back; a marvelous force, pushing at the front end of the shield, holding back the water like a giant hand.

When you are on the surface you are living under a protection against the water. The shield is only a normal atmospheric pressure. The water is under a pressure four times that much. Only 18 pounds of pressure was necessary to keep the water out of the Detroit-Windsor Tunnel shield.

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on one end of the tube, sinking it below water. That end sunk to the bottom, but when you remember that the tube is 35 feet in diameter after the concrete had been poured inside, you can see why it can't sink. At this point, you realize that the tube didn't have far to sink. With one end under water, a floatation scow was run over that end and attached to the tube by means of cables. A diver hooked the cables from the floatation scow to each side of the submerged tube end, then went up to the surface. The other end of the tube was placed on the other end, a floatation scow ran and the river was left. The tube was in place. Now we have a submerged tube weighing about 8,500 tons. Into the bottom of the trench 2 1/2 feet of sand had been dropped and graded level. Now tube section 1 was ready to be placed into the trench on the American side of the river. When section 2 was lowered into place two lugs (one on either side of the tube) overlapped similarly placed lugs on section 1. A steel pin, 5 inches in diameter, was dropped through these two lugs and a diver guided it into place. Concrete was poured over the joint (a complete collar of it) and the divers had to slip the forms into place and guide the "trench" pipe while the concrete was being poured. Out of the pipe you can see the concrete. The job was when the great section, 248 feet long and 35 feet in diameter, octagonal in shape, was dropped downstream 300 feet and swung broadside to the current over the trench. There is a two-mile current in the river and this tube, almost as deep as the river, will be pushed down stream and across the river broadside. Four concrete anchors, each weighing 25 tons, were buried deep in the bottom of the river. Two of these anchors were placed off to one side, out on midstream, opposite the downstream end of the tube, the other two were placed straight upstream from the tube. Between the upstream anchors and the tube a "puller scow"—which is a barge with engines and cables—enough to pull against the buried anchors and haul the tube back if it should drop downstream too far—was interposed.

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THE TUNNEL CONSTRUCTION STORY

